Surgical and Pathological Anatomy of the Aortic Valve and Root

Anton E. Becker

The aortic root is defined as the junctional site between the left ventricle and the ascending aorta; it contains the aortic valve leaflets. The interest in the aortic root dates back to the works of Leonardo da Vinci[1] and has not faded since. From the surgeon's viewpoint, the aortic root is often considered as part of the aorta, but, by the same token, the root may be considered part of the left ventricular outflow tract (LVOT). It ranks high amid the sites of which profound knowledge of the underlying cardiac anatomy is mandatory to understand function, both normal and abnormal.

This article will be devoted to anatomic intricacies of surgical relevance and their relationship with some selected pathological conditions.

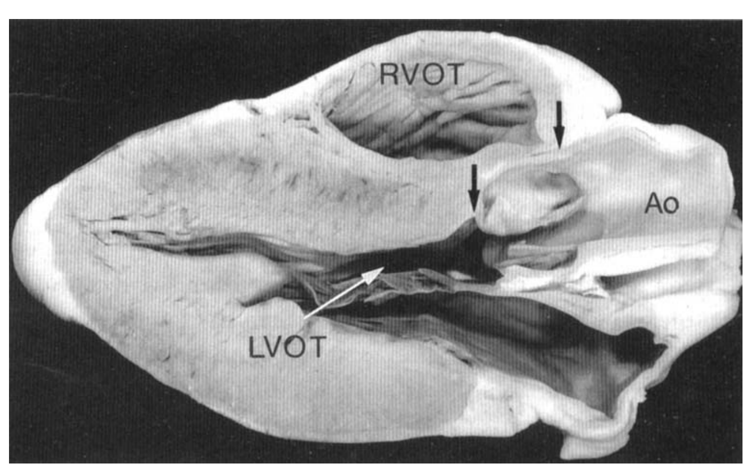
Functional Anatomy

The Aortic Root

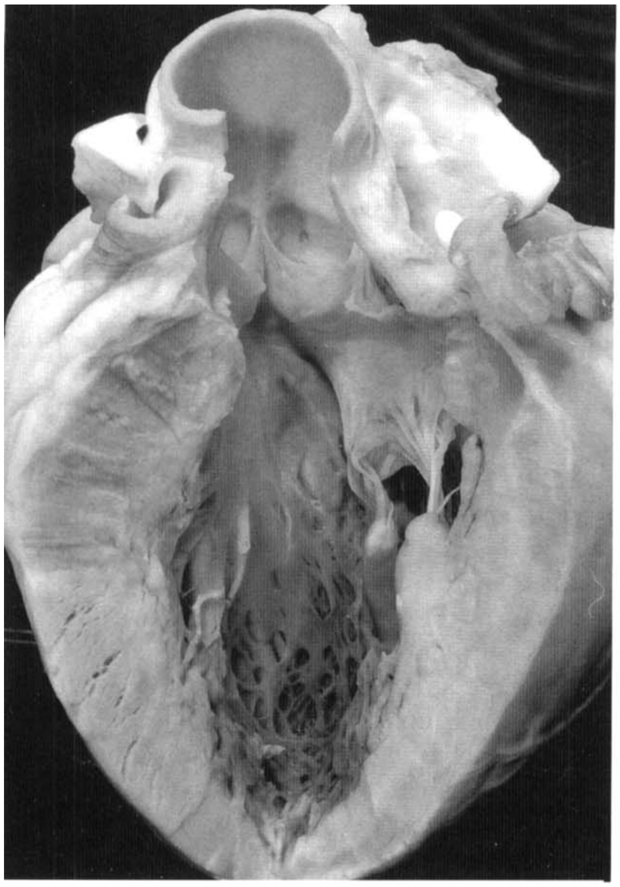
The site of junction between the left ventricle and the aorta consists of a short tube or sleeve, which is the aortic root (Fig 1). The lower part of this tube connects for approximately two thirds of its circumference to the interventricular septum, whereas the remaining part connects to the fibrous tissue of the aortic (or anterior) leaflet of the mitral valve. The upper part of the tube fuses with the ascending aorta.

The aortic valve leaflets are contained within this tube. They are attached in a semilunar fashion, thus producing valve cusps; the space delineated by a leaflet and the corresponding part of the aortic root is known as the sinus of Valsalva (Fig 2). The coronary arteries originate from the sinuses of Valsalva and the ostia are usually positioned below the level of the sinus ridge (see later). At the same time, the curved attachments of the valve leaflets create triangular spaces between the two lines of attachment of adjacent leaflets, known as the interleaflet triangles (Fig 3). These triangles are part of the aortic root, but are confined to the left ventricular cavity rather than to the aorta. The apices of the triangles form the highest point of the leaflet attachments. These points, referred to as the commissures, insert into the sinus ridge (a term, to the best of my knowledge, first introduced by Reid,[2] but also referred to as the aortic bar or ridge and the supra-aortic ridge), which marks the site of the sinotubular junction. The latter thus represents the junction between the aortic root and the ascending aorta.

Therefore, it seems that, in the strict sense, there is no aortic valve ring (or annulus). Indeed, several "rings" can be identified. First, the sinotubular junction, demarcated by the sinus ridge and the related commissural sites of the aortic valve leaflets (Fig 4A), can be identified. This plane actually represents the outlet of the aortic root. Second, the annular junction at the lower border of the aortic root, produced by the lower-most attachments of the valve leaflets (Fig 4B), can be identified. Basically, this plane represents the inlet from the LVOT into the aortic root. In general, the inlet diameter exceeds that of the outlet by 15% to 20%.[2,3] Reid,[2] using fixed human hearts, calculated an inlet/outlet radius of 1.34; Kunzelmann et al,[3] using cryopreserved normal aortic root specimens, measured



1 Cross-section through the heart of a young adult, similar to a parasternal long-axis echographic view. The aortic root, which contains the aortic valve leaflets, extends from the basal attachments of the valve leaflets to the commissural attachments at the sinus ridge (between arrows). Ao, ascending aorta; LVOT, left ventricular outflow tract; RVOT, right ventricular outflow tract.



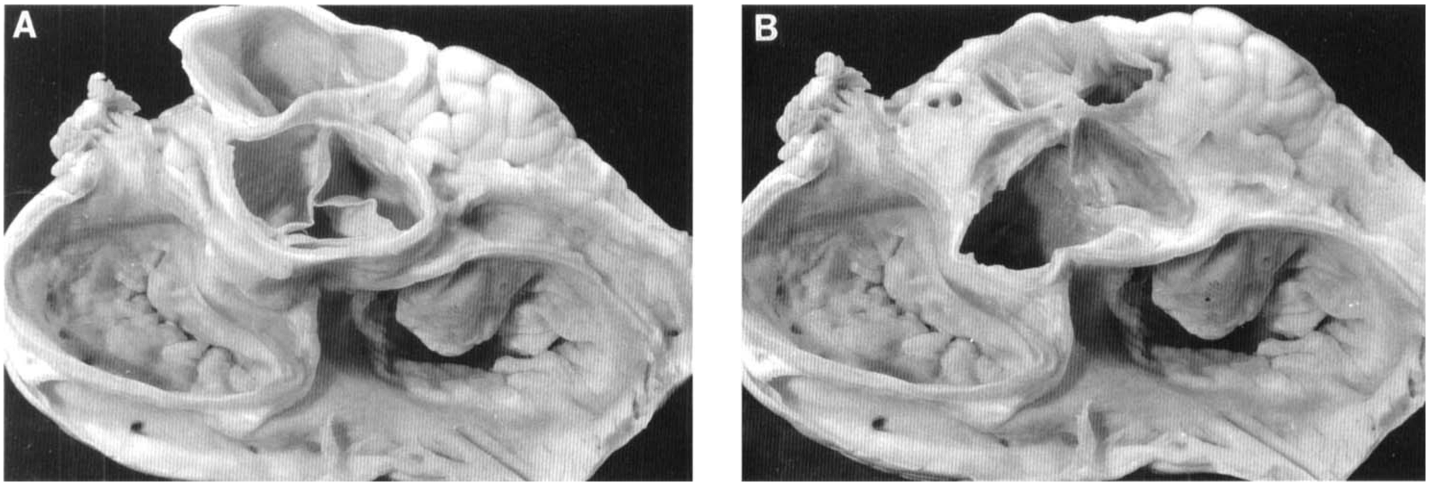
2 Opened left side of the heart with the incision extending through the aortic root into the ascending aorta. Note semilunar attachment of aortic valve leaflets and the formation of sinuses of Valsalva. Because of the curved attachments of the valve leaflets, interleaflet triangles are produced (see also Fig 3).

3 Base of the heart after removal of the atrial walls. The aortic root has been dissected and the outer wall has been removed, leaving the valve leaflets intact. Because of the curved attachments of the leaflets, interleaflet triangles are formed.

an inlet diameter of 23.4 ($\pm$1.2) mm and an outlet diameter of 18.9 ($\pm$0.9) mm. However, at both levels, annular sizes may differ markedly, depending on body habitus, age, and pathological conditions.

If one wishes, a third annulus can be identified; this is a line through the middle part of the expanded sinuses. Measurements at this level produce the largest diameter of the aortic root, which, in adults, approximates 3 cm. In fact, the inlet and outlet diameters of the aortic root, expressed as a percentage of that of the aortic sinus, have been calculated as 97% and 81%, respectively.[3] It is because of such observations that Reid[2] described the aortic root as a truncated cone. In other words, it is important to know what level of the aortic root has been measured once a diameter is produced.

It is equally important to be familiar with the complex anatomic relationships between the aortic root and its surrounding cardiac structures. Because of its deeply wedged and central position within the heart, the aortic sinuses are in close contact with both the right and left atrium and the right ventricular outflow tract (RVOT) (Fig 5). The right coronary cusp largely relates to the RVOT, but the site adjacent to the commissural junction with the noncoronary cusp may relate to the right atrium. The noncoronary cusp relates to both the right and left atrium. The left coronary cusp, in part, relates to the left atrium and faces the pericardial sac between the pulmonary trunk and the left atrial appendage. Moreover, both the noncoronary and the left coronary cusps relate intimately to the aortic leaflet of the mitral valve. These relationships are clinically relevant because disease processes may extend from the aortic root onto the adjacent anatomic structures alluded to previously. For instance, infectious endocarditis, once it spreads outside the sinuses, may produce myocardial abscesses and perforations into the surrounding structures. Of course, the same applies for infections that complicate prosthetic valves in the aortic position. Similarly, aortic dissections (see later) also may spread into the aortic root and onwards onto neighboring structures, such as the interventricular

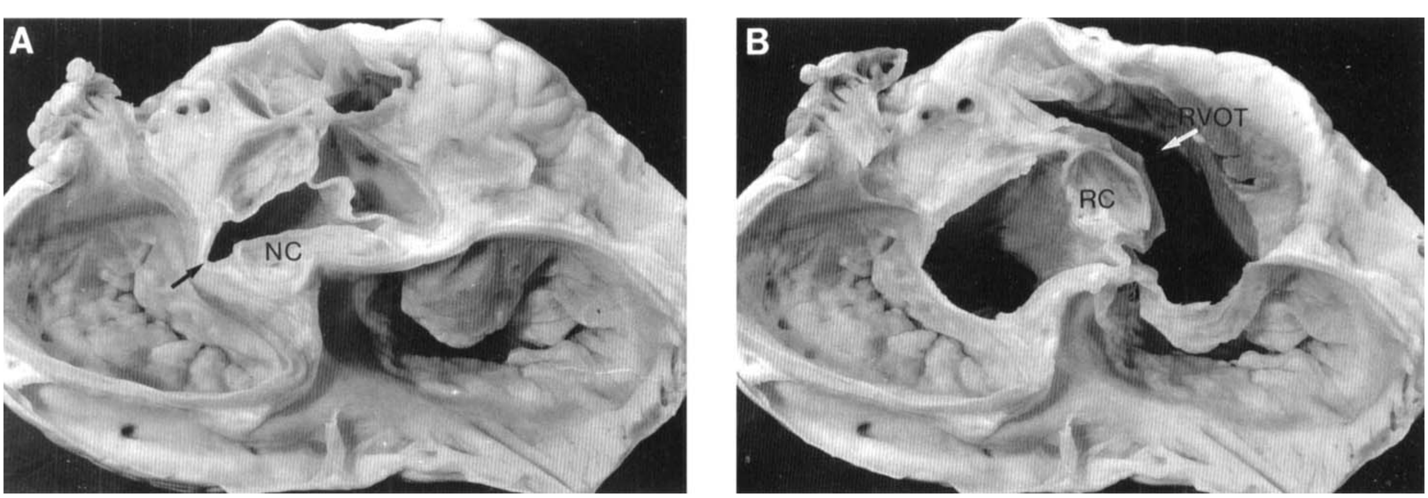


4 The basal aspect of a heart after removal of the atrial walls. Note the central and deeply wedged position of the aortic root related to both right and left atria and the right ventricular outflow tract. (**A**) Cross-section at the level of the sinus ridge and commissural attachments, thus representing the level of the aortic root outlet. (**B**) Section at the level of the basal attachments of the valve leaflets, in part to the interventricular septum and in part to the aortic leaflet of the mitral valve. This cross-section basically represents the level of the aortic root inlet.

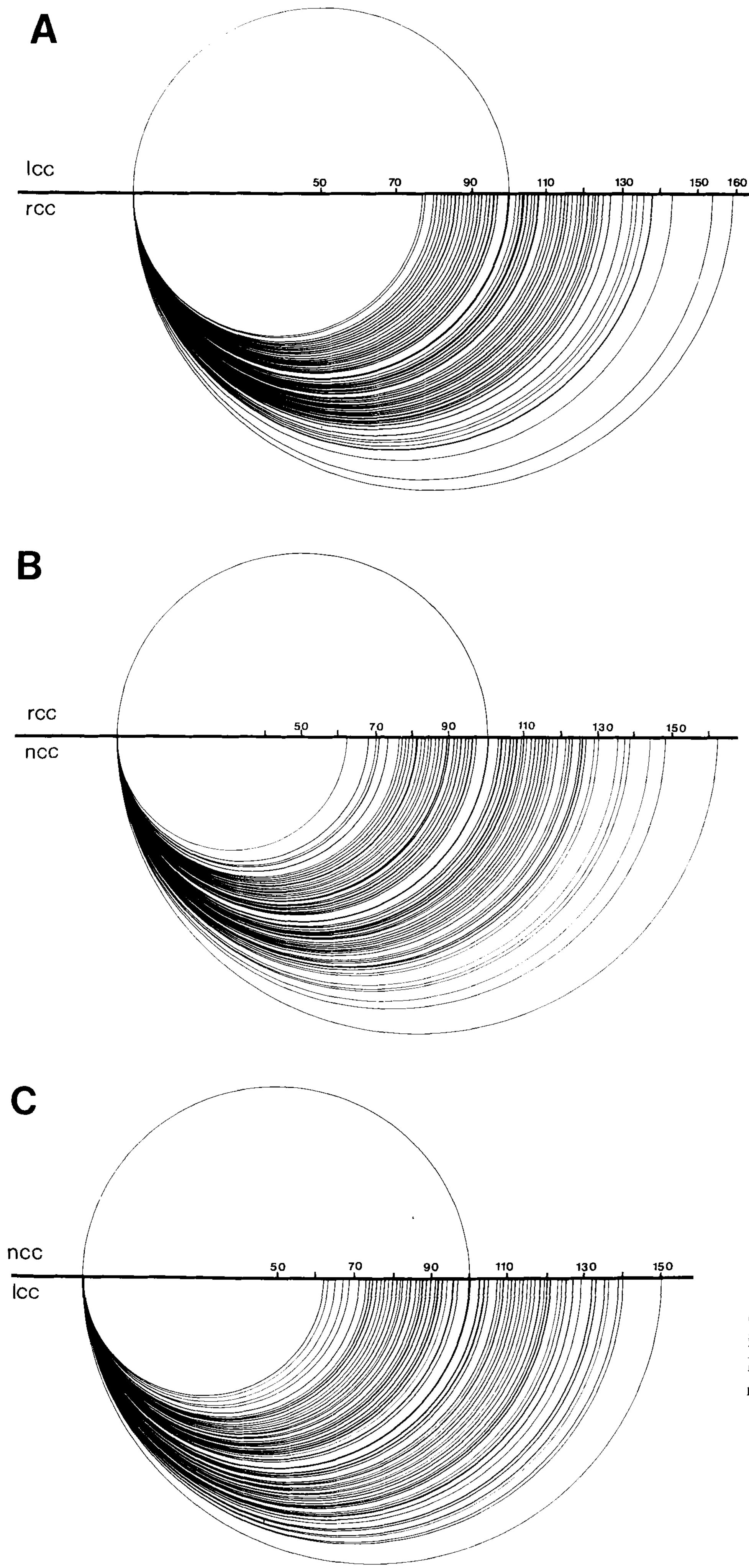
septum and the interatrial septum. Rarely, the dissecting hematoma may be so extensive that it produces atrioventricular block.[4,5]

The Aortic Valve and Leaflets

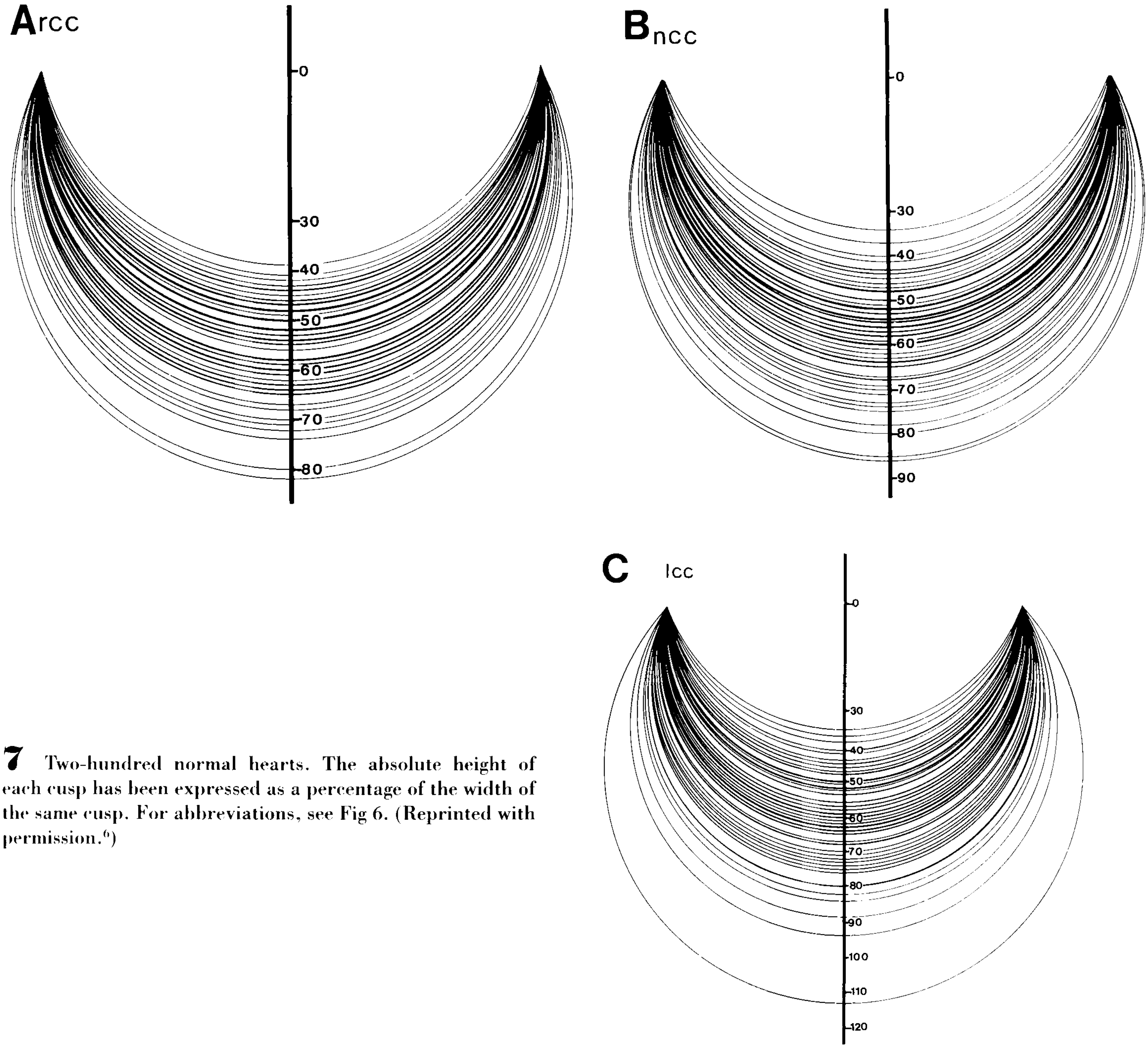
The normal aortic valve is a tricuspid structure in which the valve leaflets, together with the sinuses, the commissural sites, and the sinus ridge, form a functional unit. For instance, proper leaflet coaptation depends on proper relationships between these structures. Therefore, as one may expect, the normal aortic root has a consistent shape, albeit with variability in sizes, and shows a direct relationship between root diameter and leaflet dimensions.[3] However, not only does interindividual variation occur, but in one and the same individual marked differences exist in leaflet dimensions, both with respect to cuspidal width as well as cuspidal height. Indeed, a study of 200 normal hearts revealed that differences are the rule rather than the exception.[6] For instance, among these 200 hearts, the average width, measured between the two commissures and along the sinus ridge, for the right coronary, the



5 Additional cross-sections of the same heart as shown in Fig 4. (**A**) Note the intimate relationships of the noncoronary cusp (NC) with the right and left atria. The left coronary cusp in part faces the left atrium and in part opens into the pericardial sac between the left atrial appendage and the pulmonary trunk. Both cusps are related directly to the aortic leaflet of the mitral valve; the interleaflet triangle between both cusps has been opened (arrow). (**B**) At a lower level, the close relationship between the right coronary cusp (RC) and the RVOT is evident.



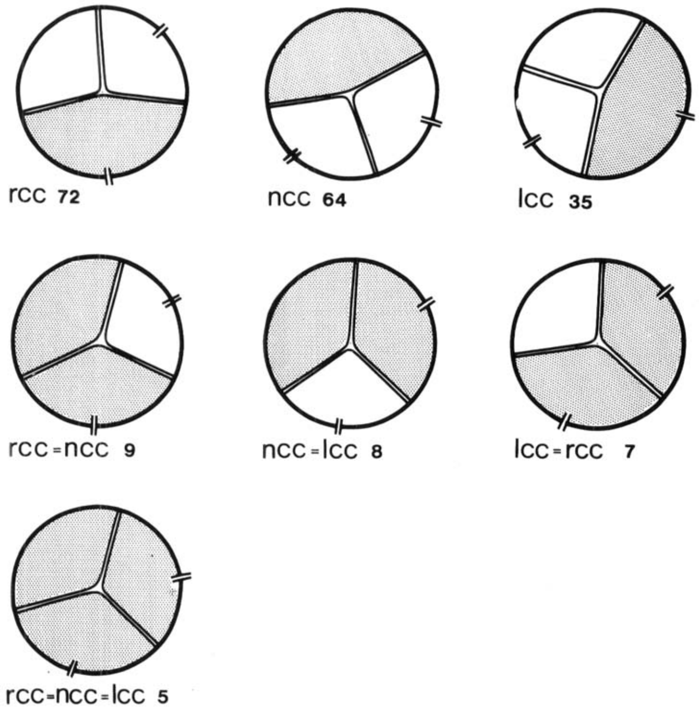
6 Two-hundred normal hearts. The absolute width of each cusp has been expressed as a percentage of a neighboring cusp. RCC, right coronary cusp; NCC, noncoronary cusp; LCC, left coronary cusp. (Reprinted with permission.[6])



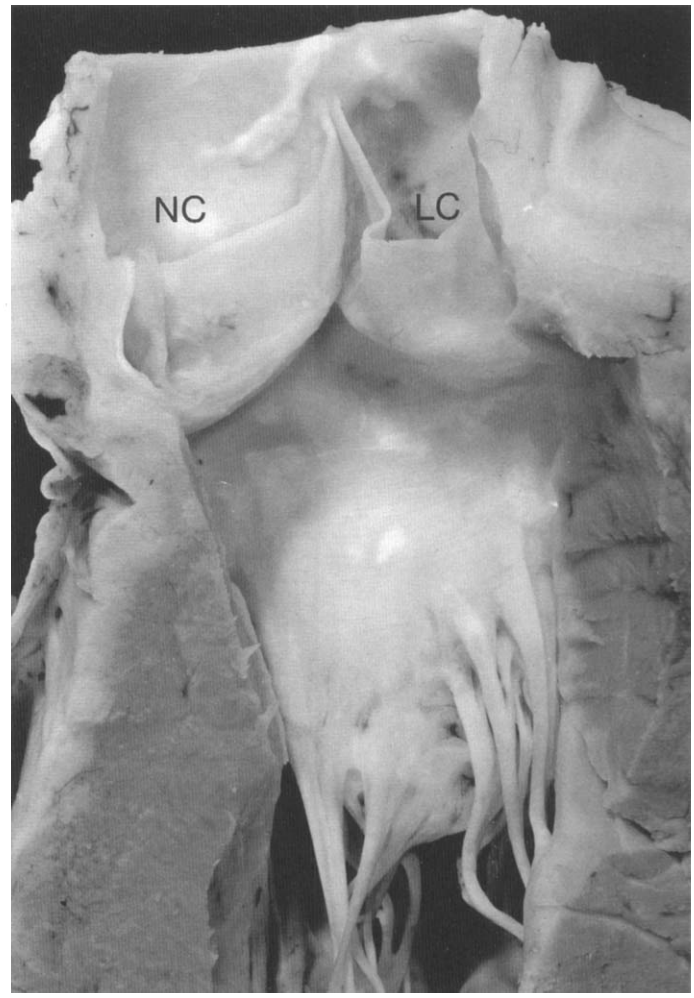
7 Two-hundred normal hearts. The absolute height of each cusp has been expressed as a percentage of the width of the same cusp. For abbreviations, see Fig 6. (Reprinted with permission.[6])

noncoronary, and the left coronary cusps was calculated as 25.9, 25.5, and 25.0 mm, respectively. However, once the absolute width of each cusp was expressed as a percentage of the width of a neighboring cusp (Fig 6), it appeared that the right coronary cusp compared with the left varied between 76% and 159%, the noncoronary cusp compared with the right coronary cusp varied between 62% and 162%, and the figures for the left coronary cusp compared with the noncoronary cusp varied between 62% and 150%. Similarly, impressive variations occurred with respect to cuspidal height. The average height, measured from the base to the free edge in the center of the leaflet, for the right coronary, the noncoronary, and the left coronary cusps was calculated as 14.1, 14.1, and 14.2 mm, respectively. When the average height was expressed as a percentage of the average width for each cusp, the percentages were 54%, 55%, and 57%, respectively. However, once the absolute height of the individual cusps was expressed as a percentage of the width of the same cusps, distinct differences appeared (Fig 7). For the right coronary cusp, the height varied between 39% and 82%, the height of the noncoronary cusp varied between 34% and 87%, and the left coronary cusp varied between 34% and 113%.

In the same study,[6] the surface area of each cusp was



8 Two-hundred normal hearts. The surface area of each cusp was calculated from the absolure figures, representing width and height. The cusp(s) with the largest proportional area (shaded) was then identified for each heart and they have been classified accordingly. Only five hearts had three equally sized cusps. (Reprinted with permission.[6])



9 The left ventricular outflow tract and aortic root have been opened to expose the area of fibrous continuity between the aortic valve leaflets of the noncoronary (NC) and left coronary (LC) cusps and the aortic leaflet of the mitral valve. A virtual line, dividing the latter into two halves, would cross the aortic root at the level of the commissure between both leaflets.

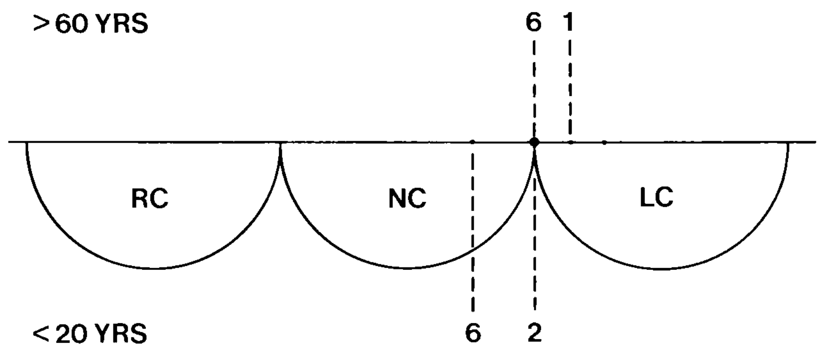
proximated to the nearest square millimeter by applying the formula $\frac{\pi}{4}ab$, derived from the ellipse and using the absolute figures representing width (a) and height (b). This allowed identification of the cusp with the largest proportional area for each heart. The results are impressive because only 5 hearts amid the 200 specimens had three cusps of equal surface area (Fig 8).

These observations have surgical relevance because there is certainly no uniformity with respect to leaflet dimensions and, hence, valvar geometry. By necessity, this dictates an individual approach tailored to the specific conditions encountered in a given patient once valve repair procedures are at stake.

The Left Ventricular Outflow Tract Related to the Aortic Valve

The LVOT is made up of a muscular component, by far the most extensive, and a fibrous component. The muscular wall consists of the interventricular septum and the fibrous component is formed by the area of fibrous continuity between the mitral valve and the aortic valve (Fig 9; see also Fig 2). In other words, the aortic valve leaflets are attached in part to left ventricular myocardium and in part to the aortic (anterior) leaflet of the mitral valve. This arrangement immediately reveals that aortic valve function cannot be considered without taking into account the functional status of the mitral valve apparatus and of the left ventricular myocardium. In fact, one could argue that the part of the aortic valve attached directly to the mitral valve is exposed to different tensile forces compared with the part attached to the myocardium. During left ventricular ejection, the "fibrous part" will be fully exposed to the systolic forces, very much like the mitral valve.

The line of attachment between the aortic and mitral valves is relatively extensive and spans approximately one third of the total aortic valve circumference. A line drawn through the middle of the aortic-mitral valve leaflet will pass through the junction at the level of the commissure between the left coronary and the noncoro-

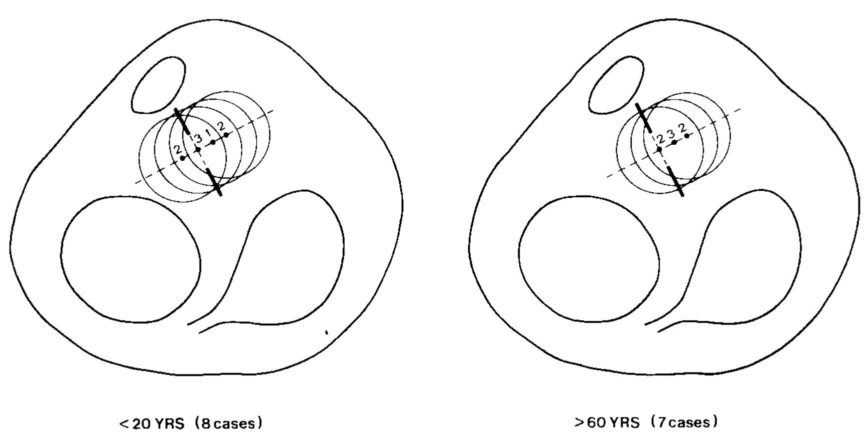


10 Drawing that illustrates the relationship between the aortic-mitral valve leaflet and the aortic valve cusps. The intersection at the level of the semilunar cusps is indicated. In hearts over 60 years of age, the line cuts through the commissure between the noncoronary (NC) and left coronary (LC) cusp in six hearts. In one instance, the line went through the left coronary cusp. In specimens under 20 years of age, the majority had the line passing through the noncoronary cusp. RC, right coronary cusp. (Reprinted by permission of Kluwer Academic Publishers.[7])

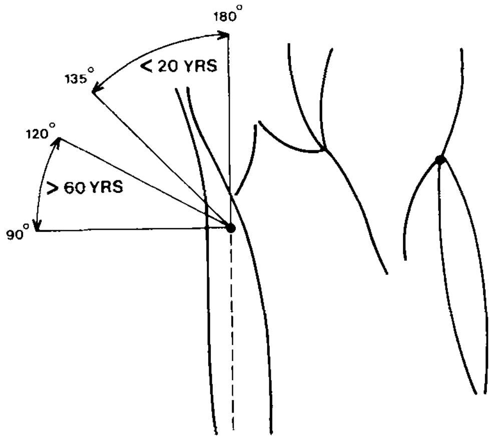
nary sinus (Fig 9). However, it seems that the detailed anatomy of the aortic-mitral valve relationship is age-dependent.[7] In individuals over 60 years of age, the midline crosses the aortic valve circumference mostly at the commissural site, but, in most young adults (under 20 years of age), the line cuts through the noncoronary cusp (Fig 10).

This observation does not stand alone, but is part of a range of age-dependent changes affecting the geometry of the LVOT. These alterations have been highlighted in a study of normal hearts, comparing those of individuals less than 20 years of age with hearts of individuals over 60 years of age.[7] Several aspects are of note.

The aortic-septal relationship is affected by age. For instance, the projected position of the aortic ostium, related to a line drawn through the outlet part of the ventricular septum, showed marked differences between young and elderly hearts (Fig 11). In the eight hearts under 20 years of age, two showed an override with the main circumference still projecting over the left ventricle. In three instances, approximately 50% was still confined to the left ventricle, whereas in the



11 Drawing of the aortic ostium in relation to the underlying outlet part of the ventricular septum. In hearts under 20 years of age, two showed the major part of the circumference on the left side of the septal line. Of the remaining six cases, three showed an almost 60% override, one an almost 75% override, and two specimens projected for almost all of the circumference to the right of the septal line. Among elderly specimens, there was not a single case in which the major part of the aortic ostium projected to the left of the septal line. (Reprinted by permission of Kluwer Academic Publishers.[7])



12 Drawing of the angle between the trabecular and outlet parts of the ventricular septum in a long-axis view. Specimens over 60 years of age show the range between 90° and 120°. Those under 20 years of age ranged from 135° to 180°. There was no overlap between the two groups. (Reprinted by permission of Kluwer Academic Publishers.[7])

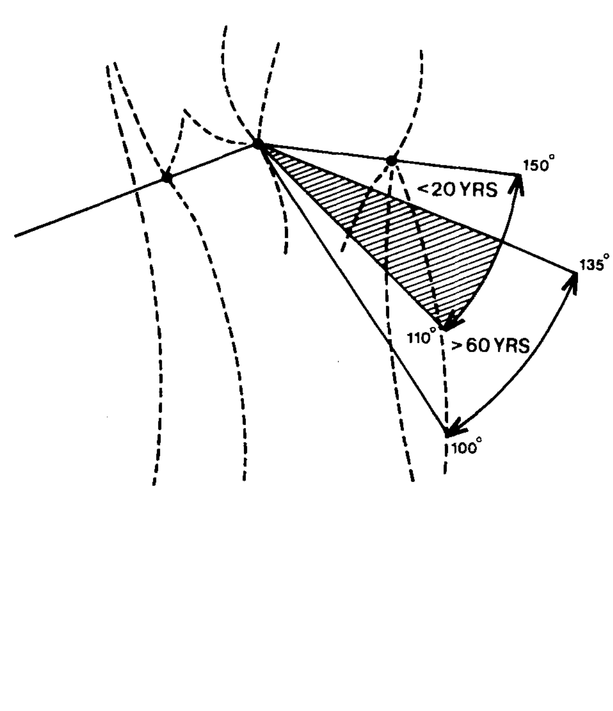
remaining three cases the major part of the ostial circumference projected to the right. On the other hand, in most elderly hearts, the major part of the ostial circumference projected to the right of the septal line.

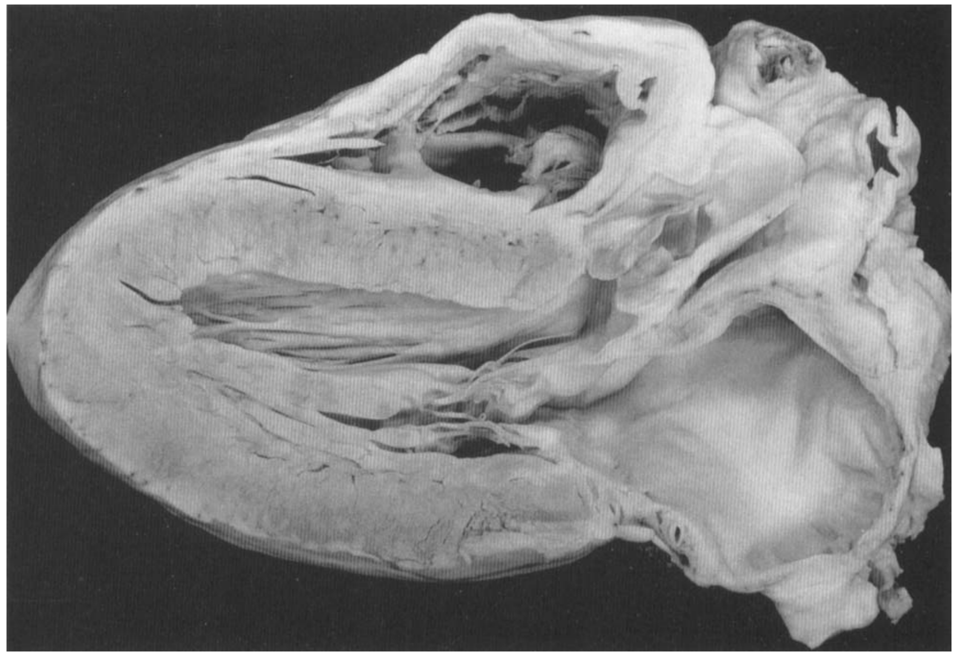
Similarly, once the septal outlet angulation is calculated by measuring the angle between the outlet part of the ventricular septum and the trabecular part of the ventricular septum, striking differences appear. In hearts under 20 years of age, the angle varied between 135° and 180°, whereas hearts over 60 years of age showed an angle that varied between 90° and 120° (Fig 12). In fact, there was no overlap between both groups in this respect.

The age-dependent changes also affect the aortic-mitral ostium angulation. In young hearts, the angle varied between 110° and 150°, whereas elderly hearts showed an angle that varied between 100° and 135° (Fig 13). The overlap zone between 110° and 135° contained 10 hearts, 5 out of each group. The relationship between the aortic-mitral ostium angulation and the long-axis septal angulation is relevant in that lesser degrees of septal angulation, which are reflected in a more pronounced left-sided bulge, are related to lesser degrees of aortic-mitral valve angulation.

Despite the observation that fluctuations occur amid young and elderly hearts, albeit often within a narrow range, some features of surgical significance stand out, such as the position of the aortic ostium in relation to the outflow part of the ventricular septum, the subaortic angulation, and the angulation between the aortic and mitral valve planes (Fig 14). It is of interest, in this context, that some young hearts may present features similar in nature to those seen more universally among elderly individuals. Hence, it is obvious that, in a proportion of young individuals, the LVOT is not a natural elongation of the left ventricular cavity, but instead curves to the right and thus produces an angled outlet. Whether this could affect the rheologic circumstances to such extent that the formation of a sigmoid-shaped LVOT is enhanced, as commonly seen in the elderly, remains a matter of speculation. Be that as it may, the differences between young and elderly hearts are striking. This applies in particular to the subaortic septal bulge, in which the measurements show no overlap between young and elderly specimens. This is surgically relevant because the angle between the aortic and mitral valve planes also tends to become less obtuse with aging. Together, these features create a setting in

13 Drawing of the angle between the aortic-mitral valve planes (Ao-MV tilt). In hearts over 60 years of age, the angle varied between 100° and 135°. In hearts under 20 years of age, the angle varied between 110° and 150°. The shaded area shows overlap. ▨ = 10 cases (5 cases >60 yrs; 5 cases <20 yrs). (Reprinted by permission of Kluwer Academic Publishers.[7])





14 Cross-section through an adult heart, similar to a parasternal long-axis echographic view. The heart is from an elderly person and shows marked septal bulging affecting LVOT geometry. Compare with Fig 1.

which the mitral ostium tends to face the septum rather than the left ventricular apical part, or, in other words, the aortic ostium tends to face the mitral valve apparatus rather than the left ventricular apex. This phenomenon may jeopardize the outcome of valve replacement procedures, particularly in elderly patients in whom both aortic and mitral valves have to be replaced.

Surgical Pathology

In the following paragraphs, a few selected topics of aortic valve pathology will be discussed as they relate to functional anatomy.

Degenerative Aortic Valve Disease

A pathological survey of surgically excised aortic valves during a 5-year period reveals that degenerative aortic valve disease is by far the most common condition (Table 1).[8] Of the 492 valves, 306 (62%) belonged to this category. Among them, the degenerative, congenitally bicupsid aortic valve was the most frequent, followed closely by the degenerative trileaflet valve. The incidence of postinflammatory ("rheumatic") aortic valve disease was low; of the 492 valves, only 131 (26.5%) were classified as such. These figures reflect the current trend from rheumatic towards degenerative aortic valve pathology in the industrialized part of the world.

TABLE 1. Classification of Aortic Valve Pathology in a Surgical Series*

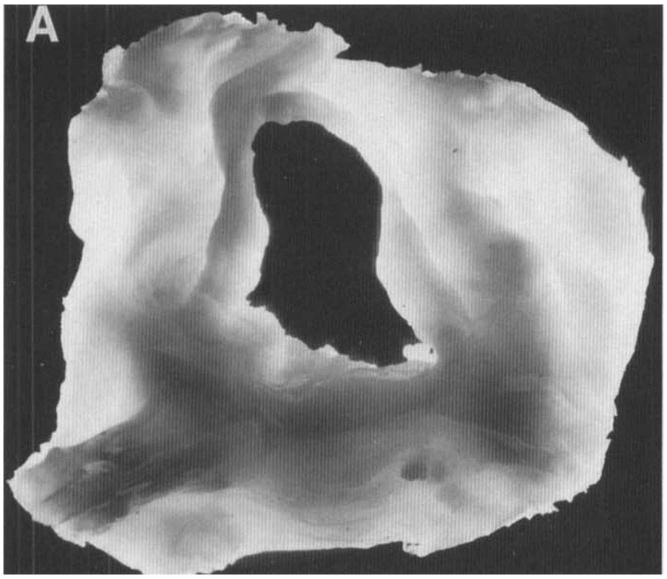
	Degenerative	Postinflammatory ("rheumatic")	Infectious Endocarditis	Total†
Unicuspid	10 (2%)	—	—	10 (2%)
Bicuspid	163 (33%)	12 (2.5%)‡	5 (1%)	180 (36.5%)
Tricuspid	133 (27%)	119 (24%)	7 (1.5%)	259 (52.5%)
Total	306 (62%)	131 (26.5%)	12 (2.5%)	449 (91%)

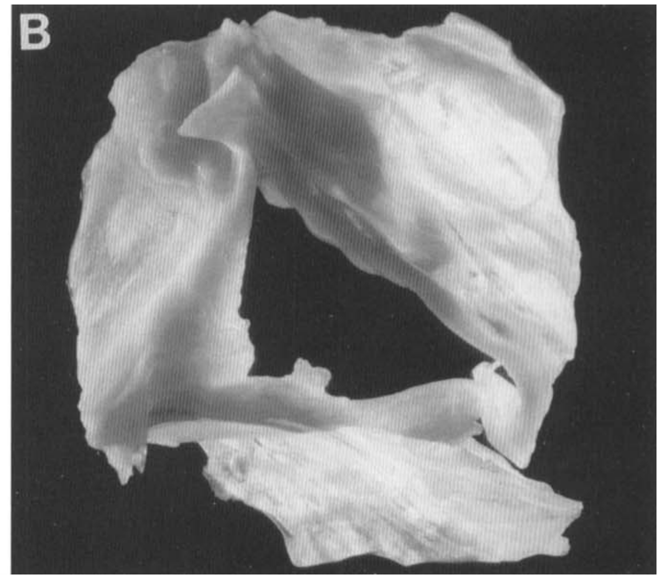
*492 valves; 1984–1989.
†Undetermined, 12 (2.5%); "normal", 31 (6.5%).
‡See Sadee A, et al.[9]

The typical pathology of a degenerated aortic valve, be it bicupsid or tricuspid, is as follows (Fig 15). The leaflets are fibrotic and often calcified, with the calcification showing preference for the sinus part of the leaflets. The calcifications are considered secondary and dystrophic in nature. They occur first in the basal part of the sinuses and tend to extend on to the underlying interventicular septum and the fibrous junction with the aortic leaflet of the mitral valve. Usually, the commissures are not affected, or are affected to a lesser degree. The underlying mechanism is generally considered to be related to processes of wear and tear.[6,10,11]

The surgical pathology of degenerative aortic valve disease clearly shows the important relationship between the mitral valve apparatus and that of the aortic valve. Not only are the aortic valve leaflets affected, but the area of aortic-mitral valve fibrous continuity also shows distinct fibrosis. Moreover, secondary calcifications often extend onto that area. From a surgical viewpoint, the extent and degree of calcification is of major importance. Attempts to decalcify leaflets may easily lead to perforations, particularly in the area of the left coronary sinus, which, in the elderly, has the most intimate relationship with the aortic leaflet of the mitral valve.

The congenitally bicuspid aortic valve may present valve regurgitation caused by a particular type of





15 Surgically excised aortic valves with the typical appearance of degeneration. (A) Congenitally bicuspid valve with conjoined leaflet containing a raphé in its basal part. (B) A trileaflet aortic valve. Both share diffuse fibrosis with early calcifications, predominantly located at the aortic site of the leaflets.

pathomorphology, the bicuspid valve with a conjoined cusp and raphé (Fig 15A). Usually, the conjoined cusp is positioned anteriorly with the right and left coronary arteries originating from it, often to either side of the raphé. The basal attachments of this conjoined cusp are almost totally confined to the underlying myocardium, whereas the posterior leaflet is the one with fibrous continuity with the mitral valve apparatus. Moreover, the width of the conjoined cusp is usually almost twice that of the second cusp. The height is not much different than the normal height of a leaflet of a tricuspid aortic valve, except for the rare case in which a central indentation exists (see later). As a consequence, the total surface area of the conjoined cusp is much larger than that of the other cusp. This feature, together with the fact that the fixation points at the commisural sites are far apart, may provide an understanding of why this type of valve morphology shows a tendency for prolapse, irrespective of the degree and extent of degenerative changes, such as fibrosis and calcification. In addition, these changes tend to dilate the corresponding part of the ascending aorta, which effects the dimensions of the aortic root at the level of the sinus ridge. Indeed, dilation of the aortic root is an important associated anomaly with bicuspid aortic valves.[12–14] Our own study of regurgitant congenitally bicuspid aortic valves revealed that dilation of the aortic root was noted clinically in 32% of the patients.[14] The relative risk of aortic valve insufficiency was significantly higher when a congenitally bicuspid valve was associated with aortic root dilation. Furthermore, the same study showed that individuals with an abnormally wide aortic root and a bicuspid valve with a central indentation are more liable to develop pure valve regurgitation.

Annuloaortic Ectasia

Annuloaortic ectasia is a disease that is poorly defined and is certainly poorly understood. The condition is characterized by excessive dilation of the aortic root, which, in particular, affects the sinotubular junction, but usually also involves the sinus part (Fig 16). In my experience, aortic root dilation is more pronounced at the site of fibrous continuity between the mitral valve and the aortic valve than it is along the muscular part, although the line of fibrous continuity itself is not affected (Fig 16). It is of interest that, under these circumstances, the aortic valve leaflets proper do not show many abnormalities other than a rolling of the free edges, which signifies longstanding valve regurgitation. Valve insufficiency seems to result from a lack of proper coaptation because of excessive and often eccentric dilation of the sinus ridge with corresponding expansion of the commissures; this is a phenomenon that is readily identified by a distinct downward stretching of the commissures.

The condition is usually referred to as noninflammatory degenerative disease of the aortic root. Medial degeneration of the aorta is often considered the underlying mechanism, with Marfan's disease as paradigm, but it seems that both medial changes and the association with Marfan's disease are inconsistent. It is because of this that the term, annuloaortic ectasia, was introduced by Cooley.[15]

16 Heart of a patient with annuloaortic ectasia. The heart is shown from above and slightly behind, after removal of the atrial walls. There is excessive dilation of the aortic root. The site of the sinotubular junction has widened extremely, which has resulted in downward stretching of the commissures. The leaflets show rolling of the cuspidal edges. Note excessive and eccentric dilation of the noncoronary sinus, related to the aortic leaflet of the mitral valve, when compared with the other sinuses.

Aortic Dissection Affecting the Aortic Root

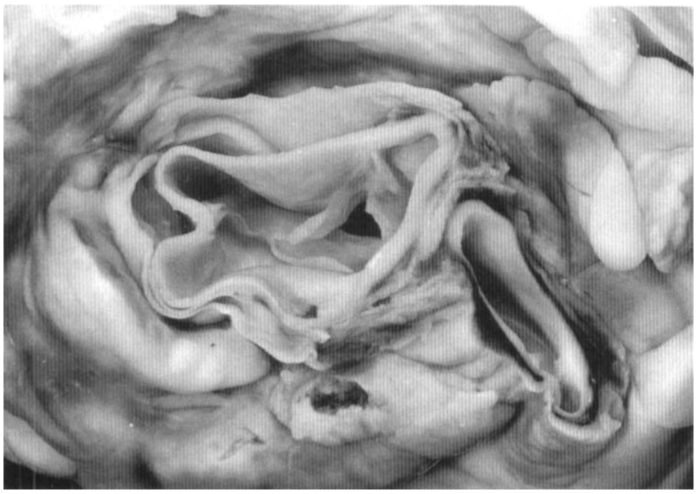
Aortic dissections with an entry site in the ascending aorta (Daily et al's type A[16]; DeBakey et al's type I and II[17,18]) usually present with a transverse angulated tear in the convexity of the ascending aorta, close to the level of the sinotubular junction. It is not uncommon to see part of the tear extending into the right coronary sinus and thus directly affecting the aortic root (Fig 17). This is important because aortic dissection may be complicated further by aortic valve regurgitation. In case the tear itself extends into the aortic root, as alluded to previously, it is obvious that the dissecting hematoma at the level of the sinus will push the wall inside, often with a flap-like detached commissure. In other instances, retrograde dissection may occur and, hence, may affect the aortic root. In this context, once more, it is important to realize that the true junction between myocardium and aorta lies somewhat halfway between the basal attachments of the aortic valve leaflets and the commissures at the level of the sinus ridge. Therefore, retrograde dissection, expanding into the aortic root, may push the commissural site (or sites) inward and may create prolapse of the corresponding leaflet(s) (Fig 18).

COMMENTS

The aortic root, which contains the aortic valve, is anatomically complex. Proper valve function depends on proper interaction of different components, such as valve leaflets, the aortic root components of the sinuses and the sinus ridge. The complexity of the functional anatomy is further highlighted by the semilunar mode of attachment of the valve leaflets. The basal parts are attached to either myocardium or fibrous tissue of the mitral valve. On the other hand, the commissural attachments insert into the aorta at the level of the sinus ridge.

In addition, marked variability occurs with respect to the dimensions of the various components involved, not

17 Aortic dissection. The tear extends into the aortic root, causing flap-like detachment of the commissure and severe aortic valve regurgitation.



18 Aortic dissection with retrograde spread of the dissecting hematoma into the aortic root. The false channel that is created pushes the commissural sites inwards and, therefore, creates prolapse of valve leaflets with aortic valve regurgitation.

only from one individual to the other, but also between valve leaflets within the same person. In addition, the geometry of the aortic root and that of the LVOT shows distinct age-related changes that affect the spatial orientation of the valvar planes of both aortic and mitral orifices.

Two important conclusions stand out. First, we need to think of the aortic valve as an aortic valve apparatus in analogy with the terminology preferred for the mitral valve. Secondly, each and every surgical approach of the aortic root and valve has to be individualized, particularly in the case of repair procedures, to optimalize the results.

REFERENCES

1. Robiscek F: Leonardo da Vinci and the sinuses of Valsalva. Ann Thorac Surg 52:328-335, 1991
2. Reid K: The anatomy of the sinus of Valsalva. Thorax 25:79-85, 1970
3. Kunzelmann KS, Grande J, David TE, et al: Aortic root and valve relationships. Impact on surgical repair. J Thorac Cardiovasc Surg 107:162-170, 1994
4. Yacoub MH, Schottenfeld M, Kittle CF: Hematoma of the interatrial septum with heart block secondary to dissecting aneurysm of the aorta. A clinicopathologic entity. Circulation 46:537-545, 1972
5. Thiene G, Rossi R, Becker AE: The atrioventricular conduction system in dissecting aneurysm of the aorta. Am Heart J 98:447-452, 1979
6. Vollebergh FEMG, Becker AE: Minor congenital variations of cusp size in aortic valves. Possible link with isolated aortic stenosis. Br Heart J 39:1006-1011, 1977
7. Middelhof CJFM, Becker AE: Ventricular septal geometry: A spectrum with clinical relevance, in Wenink ACG et al (eds): The Ventricular Septum of the Heart. The Hague, The Netherlands, Martinus Nijhoff Publishers, 1981, pp 9-22
8. Becker AE: Mitral valve pathology: Aspects of clinical relevance. Neth J Cardiol 5:75-81, 1992
9. Sadée AS, Becker AE, Verheul JA: The congenital bicuspid aortic valve with post-inflammatory disease—a neglected pathological diagnosis of clinical relevance. Eur Heart J 15:503-506, 1994
10. Edwards JE: The congenital bicuspid aortic valve. Arch Pathol 35:357-366, 1961
11. Roberts WC: The congenitally bicuspid aortic valve. A study of 85 autopsy cases. Am J Cardiol 26:72-83, 1970
12. Olson LJ, Subramanian R, Edwards WD: Surgical pathology of pure aortic insufficiency: A study of 225 cases. Mayo Clin Proc 59:835-841, 1984
13. Guiney TE, Davies MJ, Parker DJ, et al: The etiology and course of isolated severe aortic regurgitation: A clinical, pathological, and echocardiographic study. Br Heart J 58:358-368, 1987
14. Sadee A, Becker AE, Verheul HA, et al: Aortic valve regurgitation and the congenitally bicuspid aortic valve: A clinico-pathological correlation. Br Heart J 67:439-441, 1992
15. Cooley DA: Annuloaortic ectasia. Ann Thorac Surg 28:303-304, 1979 (editorial)
16. Daily RO, Trueblood HW, Stinson EB, et al: Management of acute aortic dissections. Ann Thorac Surg 10:237-147, 1970
17. DeBakey ME, Henly WS, Cooley DA, et al: Surgical treatment of dissecting aneurysms of the aorta. Analysis of twenty-two cases. Circulation 24:290-303, 1961
18. DeBakey ME, Beall AC Jr, Cooley DA, et al: Dissecting aneurysms of the aorta. Surg Clin North Am 46:1045-1055, 1966

From the Department of Cardiovascular Pathology, Academic Medical Center, University of Amsterdam, Amsterdam, The Netherlands.
Address reprint requests to Anton E. Becker, MD, Department of Cardiovascular Pathology, Academic Medical Center, University of Amsterdam, PO Box 22700, 1100 DE Amsterdam, The Netherlands.

1085-5637/96/0101-0002$5.00/0